OPTICAL SWITCH

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is based on Japanese Patent Application No. 2001-001724 filed in Japan on January 9, 2001, the entire content of which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

[0002] The present invention relates to an optical switch for reflecting or transmitting light by a switching member disposed on an optical path of an optical waveguide, and changing the running direction of light by the moving of the switching member.

2. DESCRIPTION OF THE RELATED ART

[0003] A conventional optical switch is disclosed, for example, in Japanese Unexamined Patent Publication No. 2000-121967A. In this optical switch, a micro mirror disposed on an optical path of luminous flux emitted from an optical fiber is supported by a movable plate, and the movable plate is moved by applying a voltage to move the micro mirror away from the optical path, so that forwarding and reflecting of light are changed over.

[0004] On the other hand, United States Patent No. 5,699,462 discloses an optical switch in which grooves obliquely crossing two intersecting optical waveguides are provided, bubbles are formed in the liquid filling the grooves, and bubbles are heated and moved by a micro heater. In this optical switch, the refractive index of the filling liquid and the refractive index of the optical waveguide are set nearly equal, and therefore when the liquid is placed on the optical path of the optical waveguide, the light goes straightly forward, and when bubbles are placed, the light is reflected and the running direction is changed over.

[0005] Recently, the so-called wavelength multiplex communication is developed, in which different pieces of information are put on light (carrier) of different wavelengths, and plural carriers are superposed, so that a large quantity of information can be transmitted by one optical fiber. According to such conventional optical switch, however, the lights multiplexed in wavelength are uniformly reflected or transmitted, and pieces of information put on different carriers cannot be issued separately. Accordingly, information is taken out by filtering by a branching filter, and the optical communication system having the optical switch is complicated in configuration.

[0006] Besides, the optical switch disclosed in the above mentioned Japanese Unexamined Patent Publication No. 2000-121967A requires a collimator lens in order to issue the exit light from the optical fiber to the optical fiber by reflecting or transmitting by the micro mirror. The optical switch disclosed in United States Patent No. 5,699,462 requires a micro heater for heating and a mechanism for releasing its heat. As a result, the optical switch is complicated in either case.

SUMMARY OF THE INVENTION

[0007] It is hence a primary object of the invention to present an optical switch capable of issuing wavelength multiplexed lights separately. It is also an object of the invention to present an optical switch simple in structure.

[0008] To achieve the objects, the optical switch reflecting one aspect of the invention is an optical switch for changing over the running direction of the light passing through an optical waveguide between a first direction and a second direction by moving a switching member disposed on an optical path of an optical waveguide, in which the switching member has plural switching positions, and these switching positions selectively guide each of lights of at least two different wavelengths into the first direction or second direction.

[0009] According to this configuration, by moving the switching member, the switching positions disposed on the optical path can be changed over, and lights of at least two different wavelengths can be guided selectively into the first direction or second direction. Further, by properly setting the position of the switching member, both switching positions can be kept away from the optical path. Therefore, for example, when the switching member is moved away from the optical path of the optical waveguide, the wavelength multiplexed incident light runs forward straightly, and when the switching member is disposed on the optical path of the optical waveguide, light of one wavelength passes and light of other wavelength is reflected.

[0010] Moreover, in the configuration, the switching member may be also configured to move within the groove intersecting with the optical waveguide. The groove may be filled with liquid, and in this case by moving the liquid in the

groove by a micro pump coupled to the groove, the switching member may be moved.

[0011] Further, in the configuration, each switching position may be an interference filter.

[0012] The optical switch reflecting other aspect of the invention comprises a groove intersecting with an optical waveguide and filled with liquid, a switching member movably provided in the groove, and a micro pump coupled to the groove for transferring the liquid in the groove.

[0013] According to this configuration, when the micro pump is driven, the liquid in the groove intersecting with the optical waveguide is fed, and the switching member moves in the groove. As a result, when the liquid and optical wave guide, for example, are matched in refractive index, by moving the switching member away from the optical path of the optical waveguide, the wavelength multiplexed incident light runs straightly forward, or by placing the switching member on the optical path of the optical waveguide, the incident light is reflected.

[0014] In this configuration, the micro pump may comprise a piezoelectric element, and in this case, by controlling the voltage applied to the piezoelectric element, optical switching operation may be realized.

[0015] Further, a plurality of any one of these optical switches may be disposed on a same optical path. In this configuration, wavelength multiplexed light is transmitted to one optical path having n optical switches arranged in series, and a light of a desired wavelength may be guided into a desired output port out of n output ports.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] These and other objects, advantages and features of the invention will become apparent from the following description thereof taken in conjunction with the accompanying drawing s in which:

Fig. 1 is a plan showing a state in transmission mode of optical switch in embodiment 1 of the invention;

Fig. 2 is a side sectional view of optical switch in embodiment 1 of the invention;

Fig. 3 (a) through Fig. 3 (d) are side sectional views showing a manufacturing method of main body of optical switch in embodiment 1 of the invention;

Fig. 4 (a) and Fig. 4 (b) are diagrams showing a configuration of micro pump of optical switch in embodiment 1 of the invention;

Fig. 5 is a diagram explaining operation of micro pump of optical switch in embodiment 1 of the invention;

Fig. 6 (a) and Fig. 6 (b) are diagrams showing voltage applied to the piezoelectric element of micro pump of optical switch in embodiment 1 of the invention;

Fig. 7 (a) through Fig. 7 (f) are side sectional views showing a manufacturing method of filter of optical switch in embodiment 1 of the invention;

Fig. 8 is a diagram showing transmissivity of a first interference filter of optical switch in embodiment 1 of the invention;

Fig. 9 is a diagram showing transmissivity of a second interference filter of optical switch in embodiment 1 of the invention;

Fig. 10 is a diagram showing transmissivity of a third interference filter of optical switch in embodiment 1 of the invention;

Fig. 11 is a plan showing a state of reflection mode of optical switch in embodiment 1 of the invention;

Fig. 12 is a plan showing a partial transmission state of optical switch in embodiment 1 of the invention;

Fig. 13 is a plan showing a partial transmission state of optical switch in embodiment 1 of the invention;

Fig. 14 is a diagram showing transmissivity of other interference filter of optical switch in embodiment 1 of the invention; and

Fig. 15 is a plan showing an optical switch in embodiment 2 of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0017] Referring now to the drawings, preferred embodiments of the invention are described below. Fig. 1 is a plan showing an optical switch in an embodiment of the invention, depicting a state after dismounting a diaphragm described below. An optical switch 1 has two waveguides 14a, 14b intersecting at a specified crossing angle θ disposed on a main body 8, and a groove 2 crossing the intersection 14a is formed. A sectional view along the waveguide 14a is shown in Fig. 2, in which the main body 8 is composed by forming a lower clad layer 11, a waveguide 14, and an upper clad layer 15 on a substrate 10.

[0018] A manufacturing method of the main body 8 is shown in Fig. 3 (a)

through Fig. 3(d). As shown in Fig. 3 (a), on the substrate 10 made of Si or the like, the lower clad layer 11 made of quartz or the like is formed by CVD or other process. On the lower clad layer 11, as shown in Fig. 3 (b), a core layer 12 made of quartz or the like is formed. Since the lower clad layer 11 is doped with fluorine or the like, its refractive index is larger than that of the core layer 12. The core layer 12 is coated with a resist 13 by spin coating or other process, and is patterned in a specified shape by exposure and development.

[0019] Next, as shown in Fig. 3 (c), by etching the core layer 12 by RIE or other process, a waveguide 14 of a specified shape is formed. In the case of the core layer 12 made of quartz, CHF_3 or CF_4 is used as reactive gas of RIE. After peeling the resist 13, as shown in Fig. 3 (d), an upper clad layer 15 of same material as the lower clad layer 11 is formed while doping fluorine or the like. This produces the main body 8 for guiding the incident light by the waveguide 14 being enclosed by the lower clad layer 11 and upper clad layer 15 low in refractive index.

[0020] In Fig. 2, on the main body 8, a diaphragm 16 having an electrode 18 made of ITO or the like patterned in a specified shape is adhered. On this diaphragm 16, a piezoelectric element 17 made of PZT (lead zirconic acid titanate) or the like is adhered. When a voltage is applied between the upper surface of the piezoelectric element 17 and the electrode 18, the diaphragm 16 is deformed.

[0021] Fig. 4 (a) and (b) are plan and sectional view showing essential parts of the groove 2. The groove 2 is filled with matching oil 25 equal in refractive index to the waveguides 14a, 14b (see Fig. 1). At both ends of the groove 2, there are reservoirs 21a, 21b for holding the matching oil 25 (see Fig. 1). A pump compartment 22 is formed beneath the piezoelectric element 17. The reservoir

21a and pump compartment 22 are coupled by way of a first diffuser 23a.

[0022] The pump compartment 22 is further coupled to a diffusion compartment 24 at the opposite side of the reservoir 21a by way of a second diffuser 23b. When a voltage is applied to the piezoelectric element 17 in a specific period, as indicated by single dot chain line in the diagram, the diaphragm 17 locally vibrates up and down, so that the matching oil 25 flows in the groove 2.

[0023] The width (w) and depth (d) of the first and second diffusers 23a, 23b are formed smaller than those of the reservoir 21a, pump compartment 22, and diffusion compartment 24, and therefore the passage resistance of the matching oil 25 is large. The length L21 of the first diffuser 23a is shorter than the length L2 of the second diffuser 23b. Accordingly, the matching oil 25 passing in the second diffuser 23b is nearly a laminar flow, whereas turbulence or vortex is formed in the matching oil 25 passing in the first diffuser 23a.

[0024] As a result, the passage resistance of the first and second diffusers 23a, 23b is as shown in Fig. 5. In the diagram, the axis of ordinates represents the passage resistance (unit: x 10^{12} $Nsec/m^5$), and the axis of abscissas denotes the differential pressure (unit: Pa) at both ends of the first and second diffusers 23a, 23b expressed on the logarithmic scale. Also experimental values are shown in the conditions of w = 25 μm, d = 100 μm, L1 = 20 μm, and L2 = 150 μm, and the depth of the reservoir 21a, pump compartment 22 and diffusion compartment 25 is matched with the depth (d) of the first and second diffusers 23a, 23b.

[0025] In the diagram, since the length L1 of the first diffuser 23a is short, when the differential pressure is small, the passage resistance is smaller than in the second diffuser 23b. However, in the second diffuser 23b, although the increase of passage resistance relative to the differential pressure is moderate, the

increase is substantial in the first diffuser 23a due to turbulence or vortex. Accordingly, as the differential pressure increases, the first diffuser 23a becomes larger in passage resistance than the second diffuser 23b.

[0026] Therefore, when the pressure in the pump compartment 22 is small, the matching oil 25 is more likely to flow into the first diffuser 23a, and when the pressure in the pump compartment 22 is large, the matching oil 25 more smoothly flows into the second diffuser 23b.

[0027] As understood from these results, when the voltage applied to the piezoelectric element 17 is a sharp rising sawtooth waveform as shown in Fig. 6 (a), the pressure in the pump compartment 22 instantly hikes up. As a result, the amount of matching oil 25 flowing out from the second diffuser 23b is greater than the amount flowing out from the first diffuser 23a, so that the matching oil 25 flows, in average, to the right side in Fig. 4 (a), (b).

[0028] By contrast, when the voltage applied to the piezoelectric element 17 is a mild rising sawtooth waveform as shown in Fig. 6 (b), the pressure in the pump compartment 22 increases gradually, and the amount of matching oil 25 flowing out from the first diffuser 23a is greater than the amount flowing out from the second diffuser 23b, so that the matching oil 25 flows, in average, to the left side in Fig. 4 (a), (b). In this way, the micro pump 20 is composed of groove 2, diaphragm 16, and piezoelectric element 17.

[0029] In Fig. 1, a filter 3 disposed in the groove 3, and is immersed in matching oil 25. Along with flow of the matching oil 25, the filter 3 can be moved in the groove 2. The filter 3 is composed of three interference filters 3a to 3c different in optical characteristics. A manufacturing method of the filter 3 is shown in Fig. 7 (a) to (f).

[0030] As shown in Fig. 7 (a), on a base 31 of silicon or the like, a substrate material such as fluorinated polyimide or the like is applied, heated, and cured, and a substrate 32 is formed. Next, as shown in Fig. 7 (b), a mask 33 is disposed on the substrate 32, and plural thin film materials different in refractive index are laminated by vapor deposition or the like, and an interference filter 3a is formed.

[0031] Similarly, as shown in Fig. 7 (c) and (d), thin film materials are laminated by vapor deposition or the like, and interference filters 3b, 3c are formed. Then, as shown in Fig. 7 (e), cutting off at specified positions by dicing saw or the like, the substrate 32 is separated from the base 31, and a filter 3 having interference filters 3a to 3c different in optical characteristics disposed parallel on the substrate 32 is obtained (Fig. 7 (f)).

[0032] For example, the operation is explained in the case of the optical switch having the interference filters 3a to 3c formed so as to exhibit the optical characteristics as shown in Fig. 8 to Fig. 10. Luminous flux entering the optical switch 1 consists of light of wavelength $\lambda 1$ (= 1.3 μm) and light of wavelength $\lambda 2$ (= 1.55 μm), which are multiplexed in wavelength in one optical fiber by a fiber coupler, and entered from an input port 4 (see Fig. 1).

[0033] When the optical switch 1 is put in transmission mode, as shown in Fig. 1, the micro pump 20 drives and the filter 3 is moved away from the intersection 14c of the waveguides 14a, 14b. The lights of wavelengths $\lambda 1$ and $\lambda 2$ pass through the matching oil 25 equal in refractive index to the waveguide 14a, and goes straight forward in the waveguide 14a. The lights come out from a first output port 5a.

[0034] When the optical switch 1 is in reflection mode, as shown in Fig. 11, the micro pump 20 drives and interference filter 3a of the filter 3 is placed at the

intersection 14c of the waveguides 14a, 14b. The interference filter 3a is about 0% in transmissivity at wavelengths $\lambda 1$ and $\lambda 2$ (see Fig. 8). Accordingly, the lights of wavelengths $\lambda 1$ and $\lambda 2$ entering from the input port 4 are reflected by the filter 3, and run through the waveguide 14b, and come out from a second output port 5b.

[0035] As shown in Fig. 12, as the micro pump 20 drives, when the interference filter 3b of the filter 3 is disposed at the intersection 14c of the waveguides 14a, 14b, the interference filter 3a is about 100% in transmissivity at wavelength $\lambda 1$ and about 0% at wavelength $\lambda 2$ (see Fig. 9). Accordingly, the light of wavelength $\lambda 1$ entering from the input port 4 passes through the filter 3, and goes straight forward in the waveguide 14a, and comes out from the first output port 5a. The light of wavelength $\lambda 2$ is reflected by the filter 3, and runs through the waveguide 14b, and comes out from the second output port 5b.

[0036] As shown in Fig. 13, as the micro pump 20 drives, when the interference filter 3c of the filter 3 is disposed at the intersection 14c of the waveguides 14a, 14b, the interference filter 3a is about 0% in transmissivity at wavelength $\lambda 1$ and about 100% at wavelength $\lambda 2$ (see Fig. 10). Accordingly, the light of wavelength $\lambda 2$ entering from the input port 4 passes through the filter 3, and goes straight forward in the waveguide 14a, and comes out from the first output port 5a. The light of wavelength $\lambda 1$ is reflected by the filter 3, and runs through the waveguide 14b, and comes out from the second output port 5b.

[0037] Therefore, by moving the filter 3 by driving the micro pump 20, the wavelength multiplexed luminous flux superposing carriers of plural wavelengths can be changed over in any one of total reflection, total transmission, partial transmission, and partial reflection. Further, as shown in Fig. 14, the

interference filter may be also designed in a narrow band so as to pass only light of wavelength of 1.55 μm.

[0038] According to the embodiment, wavelength multiplexed incident lights can be switched by each wavelength and issued separately, and branching filter is not particularly required, and the optical communication system can be simplified.

[0039] Instead of the filter, meanwhile, micro mirror or other switching member may be disposed in the groove. In this configuration, although wavelength selectivity is not achieved, the switching member disposed at intersection of waveguides can be moved by a micro pump using a piezoelectric element, so that an optical switch not requiring collimator lens or heat release mechanism can be realized.

[0040] Fig. 15 is a plan showing an optical switch in embodiment 2 of the invention. In this embodiment, an optical switch row 41 is formed by disposing same optical switches as in embodiment 1 in a straight line. The optical switch row 41 crosses with a waveguide 42 and waveguides 43a to 43c, and at each intersection, a same micro pump 20 as in embodiment 1 is disposed.

[0041] At the input side (left side in the drawing) of the waveguide 42, an optical fiber 44 is connected, and at the output side (right side in the drawing) of the waveguide 42, an optical fiber 45 is connected. At the output side (lower side in the drawing) of the waveguides 43a to 43c, each optical fiber of an optical fiber array 45 is connected.

[0042] When a wavelength multiplexed luminous flux superposing lights of plural wavelengths is entered from the optical fiber 44, the micro pump 20 is driven to move the filter 3 disposed in the groove 2 (see Fig. 1), so that the lights can be issued from different optical fibers depending on the wavelength.

[0043] For example, n pieces of lights multiplexed in wavelength can be directly put into 1 × n pieces of optical switches without being branched into optical fibers, and lights of arbitrary wavelengths can be issued to n pieces of optical fibers for output. Therefore, the expensive AWG used in the prior art is not needed, and the number of optical switches is curtailed, and the loss of light can be reduced.

(Examples of experiment)

[0044] The optical switch 1 of embodiment 1 was manufactured in the following specification, and the operation of the optical switch 1 was evaluated. The interference filters 3a to 3c were manufactured according to the optical characteristics shown in Fig. 8 to Fig. 10.

Table: Specification of Optical Switch 1

Main body	Substrate	Material	Silicon
	Lower clad layer	Material	Quartz
		Thickness	20 μm
		Refractive index	1.4626
	Waveguide	Material	Quartz
		Thickness	7 μm
		Refractive index	1.4670
		Crossing angle θ	10°
	Upper clad layer	Material	Quartz
		Thickness	20 μm
		Refractive index	1.4626
	Groove	Depth	100 μm
	Diffuser	Depth d × width w	25 μm × 20 μm
Diaphragm		Material	Borosilicate glass
		Thickness	70 μm
Piezoelectric element		Material	PZT
		Max. voltage	60 V
		Frequency	11 kHz
Matching oil		Refractive index	1.4626
Filter	Substrate	Material	Fluorinated polyimide
		Thickness	5 μm
		Refractive index	1.52
	Interference filter	Material	Lamination of SiO_2 and TiO_2
		Refractive index	SiO_2: 1.46, TiO_2: 2.3
		Number of layers	31
		Width	20 μm × 3
Wavelengths of incident lights λ1, λ2		1.3 μm, 1.55 μm	

[0045] As a result, lights of wavelengths λ1, λ2 entering from the input port 4 were issued from the first output port 5a in transmission mode (see Fig. 1), and from the second output port 5b in reflection mode (see Fig. 11). In the case of partial transmission and partial reflection (see Fig. 12 and Fig. 13), outputs were respectively obtained from the first and second output ports 5a, 5b, and the insertion loss at this time was 2 dB, and the extinction ratio was 30 dB. The filter 3 is moved at a speed of 2×10^4 μm/sec, and the maximum moving distance

necessary for changeover is 80 μm (20 × 4), and therefore the switching speed is 4 msec.

[0046] As clear from the explanation herein, according to the optical switch of the embodiment, since the switching member disposed on the optical path of the optical waveguide guides the light in different directions depending on the wavelengths, so that the wavelength multiplexed incident lights can be switched and issued separately depending on the wavelength. Therefore, branching filter is not needed, and the optical communication system using the optical switch can be simplified.

[0047] Further, composing the switching member by using interference filters, by moving in the groove crossing with the optical waveguides, an optical switch having a wavelength selectivity can be easily composed.

[0048] Moreover, by disposing the switching member at the intersection of optical waveguides, and by moving the switching member by a micro pump using a piezoelectric element, the optical switch not using the collimator lens or heat release mechanism as required in the prior art can be realized.

[0049] Still more, by disposing a plurality of optical switches in one optical path, the wavelength multiplexed lights can be directly put into optical switches arranged in series without being branched into optical fibers, and lights of arbitrary wavelengths can be issued to optical fibers for output. The expensive AWG (arrayed wave gating) used in the prior art is not needed, and the number of optical switches is curtailed, and the loss of light can be reduced.

[0050] Although the present invention has been fully described by way of examples with reference to the accompanying drawings, it is to be noted that various changes and modifications will be apparent to those skilled in the art.

Therefore, unless otherwise such changes and modifications depart from the scope of the present invention, they should be construed as being included therein.